

FLOW ANALYSIS EXPERIMENT AROUND A CIRCULAR CYLINDER WITH SPLITTER PLATE

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ABSTRACT

The flow past a circular cylinder has been extensively studied in the past, so as to understand the complex flow field, acting around the cylinder. The presence of boundary layer separation makes the flow highly unsteady, which leads to a phenomenon of vortex induced vibration, which can be highly damaging for the cylinder.

The major contribution drag on cylinder was due to the pressure drag, it is also observed that the interaction of vortices leads to a higher pressure drag. Therefore, the present work aims to restrict the interaction of vortices. The restriction has been brought using a splitter plate, fixed at angle $\Theta=180^\circ$. Due to the presence of the splitter plate, the two vortices in the upper and lower half of the cylinder become blind and do not interact with each other. Mainly, the present case has been studied with the Effect of the length of the splitter plate.

The measurement of surface pressure distribution, carried out in the subsonic wind tunnel at a Reynolds's number 35000 and some specified cases of splitter plate with circular cylinder. Results of the present computation were validated. The pressure distribution along the surface of the cylinder, effect splitter plate, strouhal number and time variation of lift and drag were investigated.

KEYWORDS: Circular Cylinder, Pressure Drag, Splitter Plate, Cfd Analysis & Experiment

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INTRODUCTION

Flow past a circular cylinder is a classic problem in fluid mechanics. Most of the man made things structures are bluff bodies. The studies about circular cylinder generally come under “bluff body aerodynamics” which mainly related to the study of separated flows. Some of the examples of cylindrical shapes are bridges, heat exchangers tube bundles, power transmissions, roof-top chimneys, aircraft struts, marine structures and etc.

A circular cylinder, usually experiences boundary layer separation and very strong flow oscillations in the wake region, behind the body. In certain Reynolds number range, a periodic flow motion will develop in the wake, as a result of boundary layer vortices being shed alternatively from either side of the cylinder. This regular pattern of vortices in the wake is called as “vortex sheet or von Karman Vortex Street”. It creates an oscillating flow at a discrete frequency that is correlated to the Reynolds number of the flow. The periodic nature of the vortex shedding phenomenon can sometimes lead to unwanted structural vibrations, especially when the shedding frequency matches one of the resonant frequencies of the structure; these vibrations are called as “vortex induced vibrations”, as a result, due to the periodic nature of vortex shedding the cylinder experiences’ lateral forces.

Flow Separation

The presence of the fluid viscosity slows down the fluid particles very close to the solid surface and forms a thin slow-moving fluid layer called as boundary layer. The flow velocity is zero at the surface, to satisfy the no-slip boundary condition. Inside the boundary layer, flow momentum is quite low, since it experiences a strong viscous flow resistance. If the pressure decreases in the direction of the flow, the pressure gradient is said to be favorable. However, if the pressure is increasing in the direction of the flow, it is said to be adverse pressure gradient. In addition to the presence of a strong viscous force, the fluid particles now have to move against the increasing pressure force. Therefore, the fluid particles could be stopped or reversed, causing the neighboring particles to move away from the surface. This phenomenon is called the boundary layer separation.

Flow over a Circular Cylinder

For very small values of R_e , no separation occurs. The separation first appears when R_e becomes 5, for the range of the Reynolds number $5 < R_e < 40$, a fixed pair of vortices forms in the wake of the cylinder. The length of this vortex formation increases with R_e . When the Reynolds number is further increased, the wake becomes unstable, which would eventually give birth to the phenomenon called vortex shedding, in which vortices are shed alternately at either side of the cylinder at a certain frequency. Consequently, the wake has an appearance of the vortex street. For the range of the Reynolds number $40 < R_e < 200$, the vortex street is laminar. The shedding is essentially two-dimensional, i.e., it does not vary in the span wise direction.

With a further increase in R_e , however, transition to turbulence occurs in the wake region. The region of transition to turbulence moves towards the cylinder, as R_e is increased in the range $200 < R_e < 300$. Bloor reports that, at $R_e = 400$, the vortices once formed are turbulent. Observed in the range $40 < R_e < 200$, it becomes distinctly three-dimensional in this range and the vortices are shed in cells in the span wise direction. It may be noted that, this feature of vortex shedding prevails for all the other Reynolds number regimes, $R_e > 300$

For $R_e > 300$, the wake is completely turbulent. The boundary layer over the cylinder surface remains laminar, however, for increasing R_e over a very wide range of R_e , namely $300 < R_e < 3 \times 10^5$. This regime is known as the subcritical flow regime

With a further increase in R_e , transition to turbulence occurs in the boundary layer itself. The transition first takes place at the point, where the boundary layer separates, and then the region of transition to turbulence moves upstream over the cylinder surface, towards the stagnation point as R_e is increased

In the narrow R_e band $3 \times 10^5 < R_e < 3.5 \times 10^5$, the boundary layer becomes turbulent at the separation point, but this occurs only at one side of the cylinder. So the boundary layer separation is turbulent at one side of the cylinder and laminar at the other side. This flow regime is called the critical flow regime. The flow regime and the flow asymmetry cause a non – zero mean lift on the cylinder.

The next Reynolds number regime is the so-called supercritical flow regime, where $3.5 \times 10^5 < R_e < 1.5 \times 10^6$. In the regime, the boundary layer separation is turbulent on both the sides of the cylinder. However, transition to turbulence in the boundary layer has not been completed, yet the region of transition to turbulence is located somewhere between the stagnation point and the separation point

The boundary layer on one side becomes fully turbulent, when R_e reaches the value of about 1.5×10^6 . So, in this flow regime, the boundary layer is completely turbulent on one side of the cylinder and partly laminar and partly turbulent on the other side. This type of flow regime, called the upper-transition flow regime prevails over the range of R_e $1.5 \times 10^6 < R_e < 4.5 \times 10^6$.

Drag Reduction on Circular Cylinder

The flow over circular cylinder had been subjected to intensive research for a long time. A circular cylinder produces large drag due to pressure difference between upstream and downstream direction of the flow. The difference in pressure is caused by the periodic separation of flow, over the surface of the cylinder. Periodic separation induces fluctuations in the flow and makes the cylinder vibrate. To reduce the amount of drag or the drag coefficient of a cylinder, various active and passive flow control methods have been employed and tested successfully.

One of the passive controls used for drag reduction is splitter plate.

Splitter Plate

The issue of controlling the effects of fluid flow on bluff bodies (specifically the drag force, and vortex shedding) led Roshko (1954, 1955), was to study the effects of placing an impediment in the wake of a two-dimensional or infinite bluff body, specifically a “splitter Plate”. Since then, the application and study of the splitter plate as a flow control device for two-Dimensional bluff bodies has been widespread.

The splitter plate is an example of a passive flow control technique. These techniques may be used to suppress or weaken vortex shedding, typically by attaching additional devices in the flow field (like Roshko’s splitter plate), or by trying to modify the shape of the bluff body altogether. Other example of passive control techniques includes control cylinders and small rods.

A thin splitter plate placed near to the rear of a bluff body cylinder can directly alter the cylinder wake. For the detached plate case, it is possible for the free shear layers, to roll up and interact with each other inside the gap and consequently introduce new modes of flow structure, which can result in abrupt jumps in pressure drag and vortex shedding frequency. However, when the splitter plate is attached normal to the rear surface of the bluff body splitter plate, the interaction between the two free shear layers is delayed until the end of the plate.

METHODOLOGY

Computation Methodology

Computational Fluid Dynamics (CFD) is playing an ever increasing role in missile aerodynamic design. The design of modern tactical supersonic missiles is heavily dependent upon the prediction of the vortical structures, which appear along the leeward side of missiles bodies and inside the inlet. Accurate prediction of the flow field and more precisely, the loss of total pressure in the core of the vortices is all the more needed that they generally strongly interact with wings or control surfaces located downstream. CFD has become an important tool in missile aerodynamic research.

- Gambit is the program used to generate the grid or mesh for the CFD solver.
- Fluent is the CFD solver, which can handle both structured grids, i.e. rectangular grids with clearly defined node indices, and unstructured grids. Unstructured grids are generally of triangular nature, but can also be rectangular.

In 3-D problems, unstructured grids can consist of tetrahedrals (pyramid shape), rectangular boxes, prisms, etc.

Computational Plan of Work

- The computations were done on a single cylinder, with various viscous models like laminar, spalart-allmaras turbulence model, k epsilon turbulence model and k-omega turbulent models. In order to reduce the drag coefficient, we implemented a passive control technique i.e., splitter plate was used. The splitter plate effects are studied at different positions and lengths, on the plate. Effect of splitter plate length was performed at different lengths $L/D=1, 2$, and 4 .

Experiment Methodology

Experiments are required to validate the results from computation. In experiments pressure measurement on a single cylinder and cylinder with splitter plate at Reynolds number 35000 were done.

L = Splitter plate length, D = Diameter of the cylinder, Z =spacing between cylinder and plate

Table 1: Plan of Work

Computations Conducted	Experiments Conducted
1) Single cylinder	1) Single cylinder
2) Effect of splitter plate length of $L/D=1, 2$ and 4 , $Z/D=0$.	2) Effect of splitter plate length of $L/D=1, 2$ and 4 , $Z/D=0$.

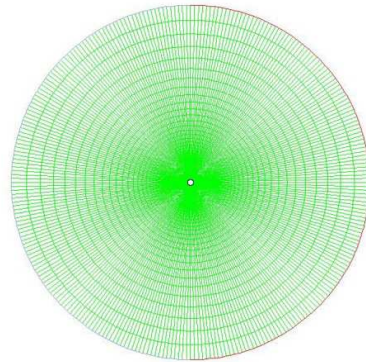


Figure 1: Grid Generation of Circular Cylinder

Experimental Models



Figure 2: Fabricated Model of Circular Cylinder



(a) Cylinder with Plate b) Cylinder with Plate c) Cylinder with Plate
 $Z=0, L/D=1$ $Z=0, L/D=2$ $Z=0, L/D=4$

Figure 3: Fabricated Model of Circular Cylinder with Splitter Plate

RESULTS

Computation Results

Initially, computations were performed over a circular cylinder of diameter 30mm at Reynolds's number, equal to 35000 by using software's 'GAMBIT' and 'FLUENT'. Then the results were compared with the experiments performed on circular cylinder body of the same diameter, 30mm and at same Reynolds's number 35000. In order to observe the effects of wake on the drag, a splitter plate was used so that the separated vortex will not be able to interact with each other. The splitter plate can also be used as a passive control technique. All the experiments and computations were carried out at subsonic speed velocity of 17 m/s.

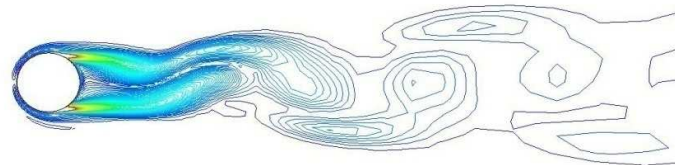


Figure 4: Contour Plots of Instantaneous Vorticity on Single Cylinder at Reynolds's Number=35,000

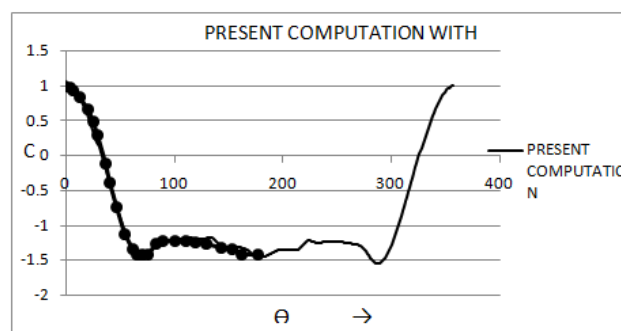


Figure 5: Time Averaged Distribution of C_p of Present Computation with Igarashi^[1] at Reynolds No 35000.

Table 2: Comparison of Results of Present Computation with Igarashi^[1] Literature

	St No	Pressure Coefficient (Drag)	Viscous Coefficient	Mean Drag Coefficient
Present results-computation	0.218	0.99	0.014	1.01
Igarashi ^[1]	0.212			1.12

The table gives the computation result of coefficient of drag, C_D value is 1.01 and the Igarashi^[1] literature value is 1.12 and there is a good agreement between the results.

Cylinder with Splitter Plate

The major contribution of drag on cylinder is due to the pressure drag, it is also observed that the interaction of vortices leads to a higher pressure drag. Therefore, the present work aims to restrict the interaction of vortices and observe their effect on the body. The restriction has been bought using a splitter plate fixed at angle $\phi=180^\circ$. Due to the presence of splitter plate, the two vortices in the upper and lower half of the cylinder become blind and do not get to interact.

Following cases have been aimed in the present section.

Effect of length of splitter plate attached with the cylinder at $\Phi=180^\circ$

Effect of Length of Splitter Plate Attached with the Cylinder

Computations were made using fluent, with the splitter plate fixed at angle $\Phi=180^\circ$ at Reynolds's number 35000. In each case, the length of the splitter plate is varied in terms of the diameter of the cylinder. The lengths of the splitter plate are $L/D=1, 2$ and 4 . Where L =length of the splitter plates and D =diameter of the cylinder.

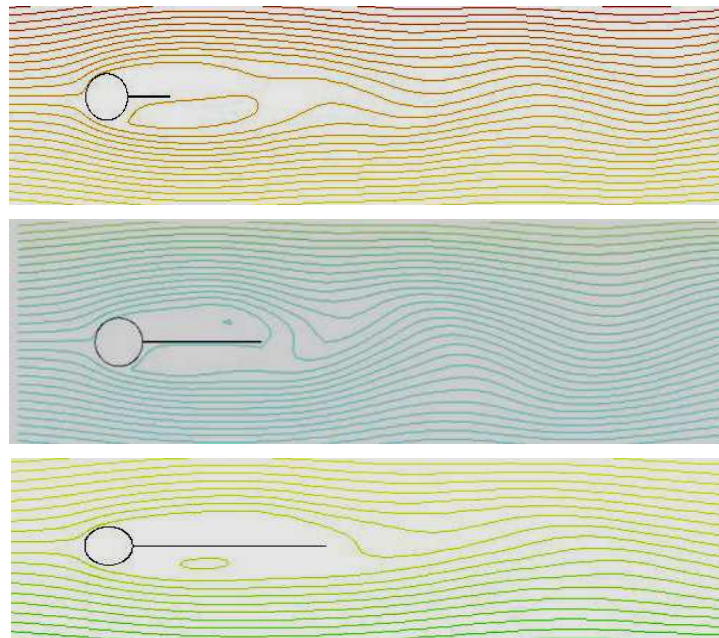


Figure 6: Stream Line Pattern over A Cylinder with Splitter Plate at $Z=0$ and $L/D=1, 2$ and 4 At Reynolds's Number 35,000

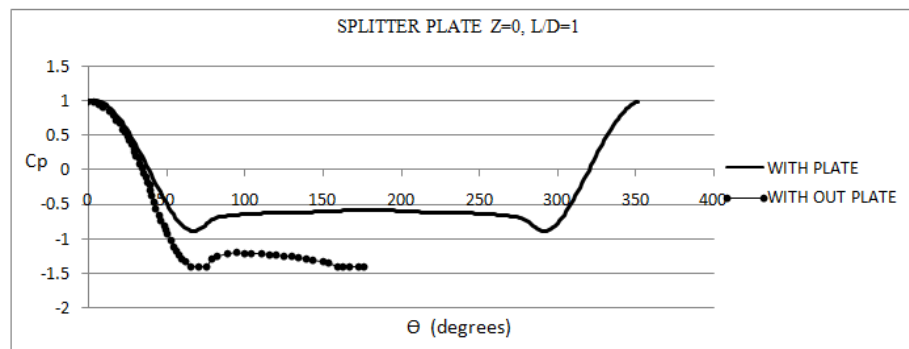


Figure 7: Cp Distribution of Cylinder with Splitter Plate $Z=0$, $L/D=1$ and Single Cylinder

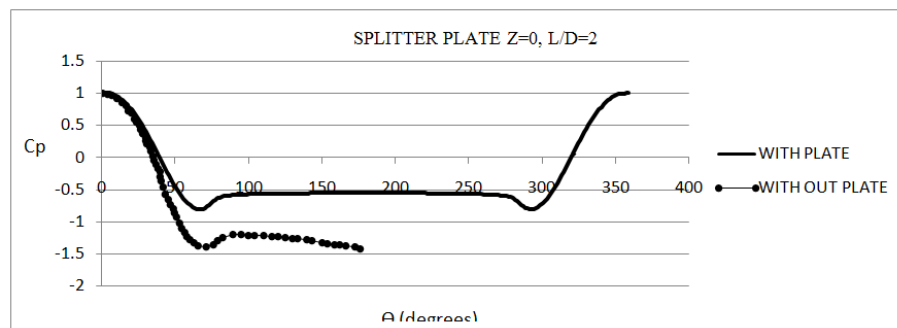


Figure 8: Cp Distribution of Cylinder with Splitter Plate $Z=0$, $L/D=2$ and Single Cylinder

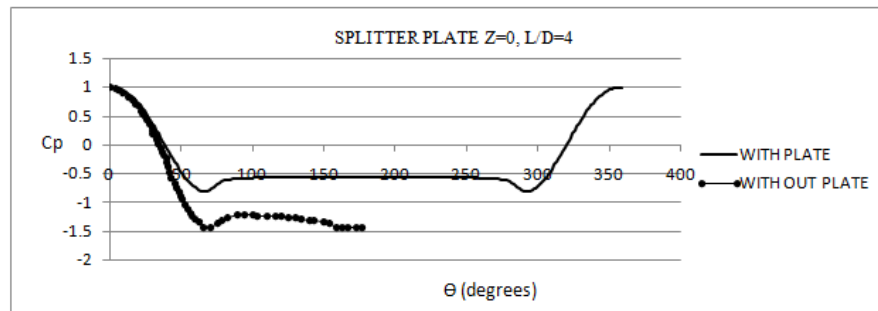


Figure 9: Cp Distribution of Cylinder with Splitter Plate $Z=0$, $L/D=4$ and Single Cylinder

Table 3: Computation Results of Cylinder with Different Splitter Plate Lengths

SPLITTER PLATE LENGTH	FREQUENCY	NET DRAG COEFFICIENT	% CHANGE IN NET DRAG COEFFICIENT
$L/D=1$	87.4	0.765	25%
$L/D=2$	81.6	0.7501	26%
$L/D=4$	56.6	0.7286	29%

EXPERIMENT RESULTS

The experiments are conducted on a circular cylinder of diameter 30mm at Reynolds's number, 35,000 on the subsonic wind tunnel. There are total 24 ports on the cylinder, which are at equal angle of 15° . All the ports were connected to the pressure sensor box. The pressure sensor box was connected to the data acquisition card of the computer. The values at each and every port were given by lab view software.

Comparison of Computation Results with Experiment

Experiment on single cylinder has given the drag coefficient value of 1.015 which is close to the drag coefficient of the computation results. From the figure 10, we can observe the trend of C_p distribution of experiment and computation results.

For a Single Cylinder

Table 4: Comparison between Computation and Experiment Result of Single Cylinder at Reynolds's Number 35000

	NET DRAG COEFFICIENT
COMPUTATION	1.011
EXPERIMENTS	1.015

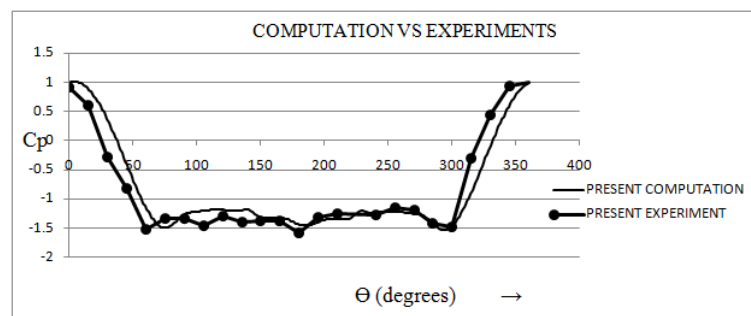


Figure 10: Cp Distribution Comparison of Computation Results with Experiments for Single Cylinder Reynolds's Number 35000

Cylinder with Splitter Plate

The experiments of the cylinder with splitter plate were done in some specified cases, out of all the computations. For the effect of length case, the experiments were carried out at $Z=0, L/D=1, 2$ and 4 .

Table 4: Comparison of Computation and Experiment Results for Cylinder with Splitter Plate at Diff Splitter Plate Lengths

SPACE BETWEEN THE CYLINDER AND BODY	SPLITTER PLATE LENGTH	COMPUTATION (NET DRAG COEFFICIENT)	EXPERIMENT (NET DRAG COEFFICIENT)
$Z=0$	$L/D=1$	0.7650	0.8381
$Z=0$	$L/D=2$	0.7501	0.7960
$Z=0$	$L/D=4$	0.7586	0.7512

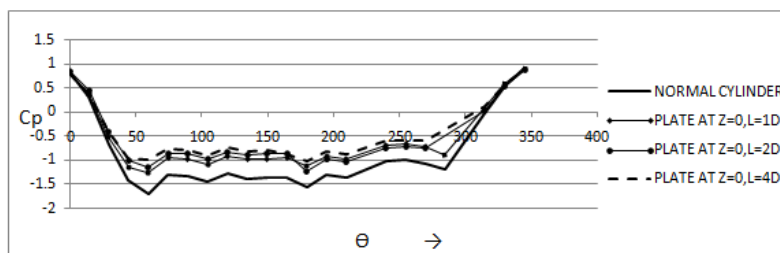


Figure 11: Cp Distribution Comparison of Experimental Results of Single Cylinder with Diff Cases of Splitter Plate Lengths.

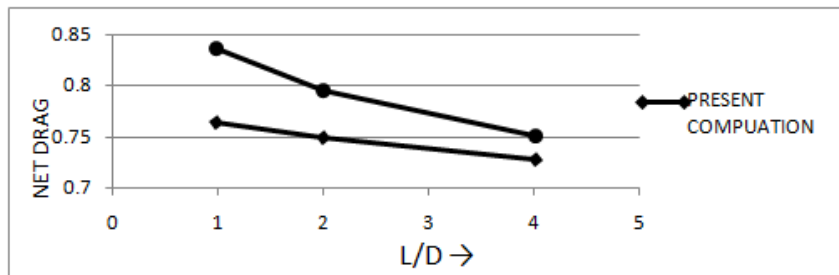


Figure 12: Comparison of Experimental Results with Computation Results of Single Cylinder with Plate L/D=1, 2 and 4

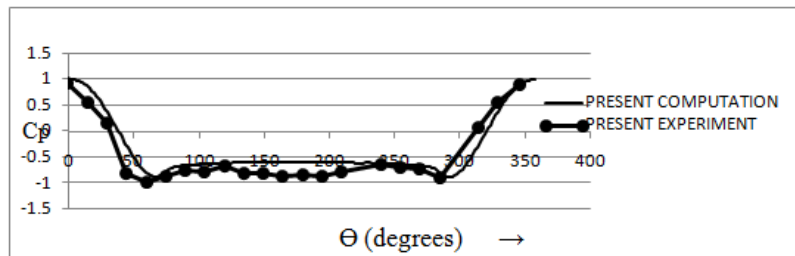


Figure 13: Comparison Experiment and Computed Pressure Distribution for Cylinder with Splitter Plate at L/D=1

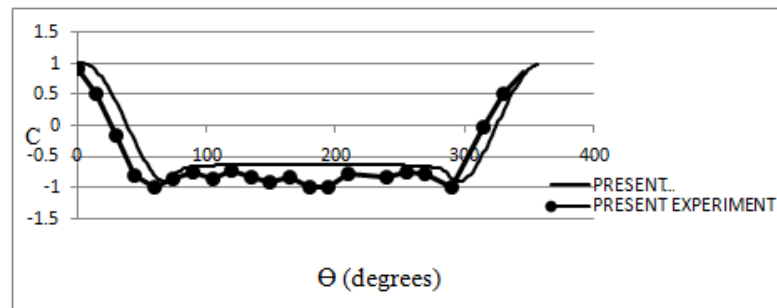


Figure 14: Comparison Experiment and Computed Pressure Distribution for Cylinder with Splitter Plate at L/D=2

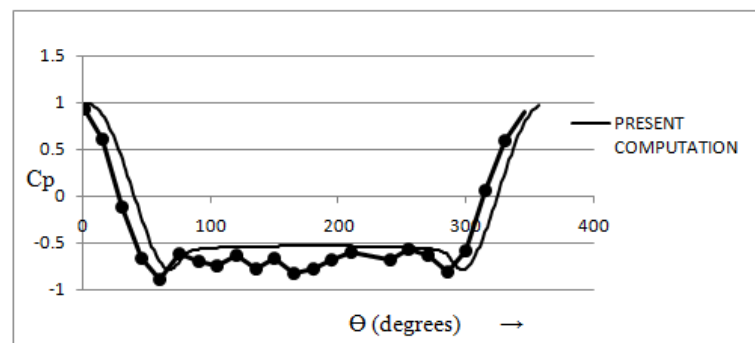


Figure 15: Comparison Experiment and Computed Pressure Distribution for Cylinder with Splitter Plate at L/D=4

CONCLUSIONS

Numerical simulation was carried out, for flow over a circular cylinder at Reynolds number 35000 and the splitter plate with the single cylinder. The experiments were conducted on single cylinder and specified models of splitter plate with cylinder. The effect of splitter plate of cylinder on drag and frequency has been observed.

A number of important conclusions were made in this investigation.

- Computation made on single cylinder revealed the pressure of vortex induced vibration as revealed in previous studies.
- The introduction of splitter plate at $\Phi=180^\circ$ altered the wake and hence, the drag forces and frequency of vortex shedding changed.
- Increase in length of splitter plate at $Z=0$, decreased the drag on the cylinder.
- Agreement between the computed and measured results were reasonably good.

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